Executive Summary

This study evaluates, using rigorous statistical analysis, the effect of meteorological conditions on ozone levels in the Houston non-attainment region. Special attention is paid to the determination of background ozone, the representation of a wide variety of meteorological predictors consolidated into principal components, and the separation of meteorological effects in the evolution of annual average background and locally contributed ozone since 1998. The primary results of the study are listed below.

Chapter 1: Partitioning of Background and Locally Contributed Ozone

1. Partitioning ozone into background and locally contributed components, as in our previous conceptual model reports (hereafter collectively designated NG05), is a viable method of examining how different meteorological factors affect ozone in different ways. It is appropriate, and consistent with the conceptual model introduced in NG05, to constrain the background ozone to be observed upwind of the city center.

2. The constraint that background ozone be observed upwind of the city center has little effect on the overall results from NG05. It raises estimates of background ozone just 1-2 ppb in winter, even less during the spring maximum, and has almost no effect on estimates of background ozone during the fall maximum.

Chapter 2: Meteorological Predictors

3. The relationship between regional transport and all types of Houston ozone, assessed using the principal components of the regional winds, is strongest when the regional winds from 1000 mb at 18 UTC are considered. The domains within which the transport wind patterns are best evaluated are very similar for each type of ozone, with the ideal regions for background and locally contributed ozone both falling within the ideal region for peak ozone.

4. The first few principal components of the ideal regional winds for Houston are similar for all types of ozone. Ozone is enhanced by offshore flow (presumably opposing the mean wind to create stagnation), along-shore flow from the northeast (presumable advecting more precursors into the region than southwesterly flow), and high pressure over the region (presumably due to the lower mixing heights and clear skies that accompany high pressure). The largest difference between meteorological influences on background and locally contributed ozone is that background ozone is positively correlated with a north-to-south frontal passage, while any frontal passage causes a decrease in peak and locally contributed ozone. This is consistent with enhanced advection of precursors into the entire region.

5. Characteristics of the sea-breeze circulation are important potential predictors of ozone concentrations in the Houston region.

Chapter 3: Modeling Ozone as a Function of Meteorology

6. Principal component analysis is an effective means of dealing with both the large number of predictors and the high level of correlation among them. The only notable disadvantage of principal component analysis is that it makes interpretation of the results complicated.

7. Ideal and convenient transformations were found for each type of ozone in Houston. Peak ozone is best modeled using a log transformation, background ozone using a square root transformation, and locally contributed ozone using a cube root transformation. Both the log and square root transformations have been widely applied to ozone data in past studies.

8. Fitting linear regression models with interactions among the principal components is a viable solution to dealing with the problems that would arise when linear regression is applied without interaction terms, such as residual dependence on values of predictor and predicted values.

9. Of the 13 principal components that comprised the predictor set in Houston, 3 were dominated by thermodynamic predictors such as temperature, solar radiation, and humidity (principal components 1, 6, and 10), 3 were dominated by transport (wind) predictors (principal components 4, 8, and 12), and 1 was sea-breeze dominant (principal component 13), while the rest were fairly balanced between thermodynamic and transport predictors.

10. Principal components weighted toward thermodynamic quantities were more valuable modeling peak ozone (particularly principal component 1), those weighted toward transport were most valuable modeling background ozone (particularly principal component 4), and locally contributed ozone was roughly an even balance of both. Wind speed is included in the "transport" predictors, which is likely why locally contributed ozone is dependent on transport. The relative importance of transport predictors on background ozone lends credibility to the methodology for partitioning the peak ozone into estimates of background and locally contributed ozone.

11. Meteorological predictors explain a larger percentage of the variability in peak ozone than in background or locally contributed ozone, and explain the smallest percentage of the variability in background ozone. This may just be an artifact of the transformations employed; the square root transformation for background ozone leaves behind the most variance to be explained, while the log transformation for peak ozone leaves behind the least variance. This may also be due to the need for favorable meteorological conditions in order for high ozone concentrations to develop regardless of transport or local emissions.

Chapter 4: Trend Estimation

12. There was a statistically significant decrease in Houston peak ozone during the period 1998-2007 regardless of the model used (linear trend and quadratic trend both with and without meteorology, categorical by year with meteorology, and time series without meteorology). The importance of meteorology to peak ozone is apparent in the categorical and quadratic models; meteorologically adjusted ozone peaked in 2003 and declined thereafter, while non-adjusted ozone (though quite noisy) generally decreased linearly during the entire period. The meteorological models report the smallest decrease in peak ozone during the period (3.67 to 3.99 ppb), but because of their improved precision over the non-meteorological models they also report the largest decrease in peak ozone at the low end of the 95% confidence intervals (2.18 to 3.13 ppb).

13. There was a statistically significant decrease in Houston background ozone during the period 1998-2007 regardless of the model used. The importance of meteorology to background ozone is apparent in the categorical and quadratic models. Both meteorologically adjusted and non-adjusted background ozone peaked in 1999, after which the meteorologically adjusted ozone reached a minimum in 2001 before rising to a secondary peak in 2005 and ending in 2007 around the same level as the 2001 minimum. Meanwhile non-adjusted ozone (though quite noisy) generally decreased linearly from 1999-2007. The estimated decrease in background ozone from 1998-2007 based on the meteorological models is between 2.57 and 3.46 ppb, while the estimated decrease from the non-meteorological models is generally slightly larger but less precise.

14. There is evidence to suggest a potentially significant increase in Houston locally contributed ozone during the period 1998-2007, though locally contributed ozone, whether meteorologically adjusted or not, peaked in 2001 and decreased after that. Not controlling for meteorology, there was no significant change in Houston locally contributed ozone during the period. Controlling for meteorology, the results suggest that locally contributed ozone increased between 1.01 and 1.70 ppb from 1998 to 2007, though there was a statistically significant decrease from 2001 to 2007. Compared with peak and background ozone, trends in locally contributed ozone are least affected by controlling for meteorological conditions. This suggests that locally contributed ozone may be more dependent on non-meteorological factors such as emissions, particularly upsets.